GLOBAL GEOGRAPHIC DATABASE IN SUPPORT OF EOS MISR DATA PROCESSING*

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ABSTRACT

This paper will describe the production of the Ancillary Geographic Product (AGP) in support of the Earth Observing System (EOS) Multi-angle Imaging SpectroRadiometer (MISR) instrument data processing. The AGP is essentially a global database of geographic properties, tailor-cd to the needs of the MISR mission, The AGP consists 01 parameters on either 1.1 or 17.6 km spacings reporting average scene elevation, point elevation, standard deviation 01 elevation, slope gradient, slope aspect, land/water identifiers, and other parameters specific to MISR needs. The elevation and elevation-derived parameters come primarily from a degraded resolution version 01 the Defense Mapping Agency (DMA) Digital Terrain Elevation Dataset (DTED). Land/water identifiers were supplied by the DMA World Vector Shoreline (WVS). The parameters are reported in a pre-determined Space-Oblique Mercator (SOM) map projection which matches the storage of other data from MISR. The AGP is made up of 233 parts, corresponding to the predicted 233 repeat orbits of the EOS AM-1 spacecraft. Within each of the 233 AGP orbits, the data is broken up into equal-area blocks along the swath, in an organizational scheme analogous to the Landsat Worldwide Reference System (WRS) Path and Row storage.

1.0 INSTRUMENT OVERVIEW

MISR (Diner et al., 1993) will be launched into polar orbit on the Earth Observing System (EOS) AM 1 spacecraft in June 1998. It contains nine push-broom cameras to observe at fixed view angles, relative to the surface normal, of 0° (nadir), 26.10, 45.6°, 60.0°, and 70.5° fore and aft of nadir using charge-coupled device (CCD) line arrays filtered to 443, 555, 670, and 865 nm. The line arrays consist of 1504 photoactive pixels plus 16 light-shielded pixels per array, each 21 μm square. The overlap swath width seen in common by all nine cameras is 360 km, which provides global multi-angle coverage of the entire Earth in 9 days at the equator, and 2 days at the poles. The cross-track instantaneous field of view (IFOV) and sample spacing of each pixel is 27.S m for all of the off-nadir cameras, and 250 m for the nadir camera. Along-track IFOV's depend on view angle, ranging from 250 m in the nadir to 825 m at the most oblique angle. Sample spacing in the along-track direction is 275 m in all cameras.

2.0 PROCESSING CONTEXT

The AGP is essentially a global database of geographic properties, tailored to the needs of the MISR mission. The AGP is utilized in the creation of all MISR science retrieval products throughout the mission and is required for the interpretation of those products. The parameters in this product are reported in a Space-Oblique Mercator (SOM) map projection. The map resolution of the projection is 1.1 km; this defines the horizontal sampling for most of the parameters. The horizontal datum, or surface-basis, for the projection is the WGS84 ellipsoid. This map projection and surface-basis is identical to what will be used for all the MISR science retrieval parameters.

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The AGP shall consist of 233 parts (of one or more files), corresponding to the 233 repeat orbits of the EOS AM- 1 spacecraft, The length and width covered by the AGP needs to be large enough to contain the maximum overlap width of the swath seen by all nine MISR camera views. This width varies per latitude to a minimum near the poles and a maximum of 378 km near the equator. The length of the AGP covers the maximal starting and ending points of the MISR instrument mapping of the surface. Since a mapping swath runs from terminator to terminator for every orbit, the AGP must run from the terminator of the summer solstice at the north end of the orbit and the terminator of the winter solstice at the south end.

3.0 PROCESSING OUTLINE

The first step in the creation of the AGP is the construction of the DEM Intermediate Dataset (DID). The DID is the basic input dataset required for the creation of the MISR Ancillary Geographic Product (AGP). The DID is essentially an elevation database for the entire Earth stored in a Plate Carrée (simple cylindrical) projection at 3 arc second resolution. The elevation values come primarily from the. Defense

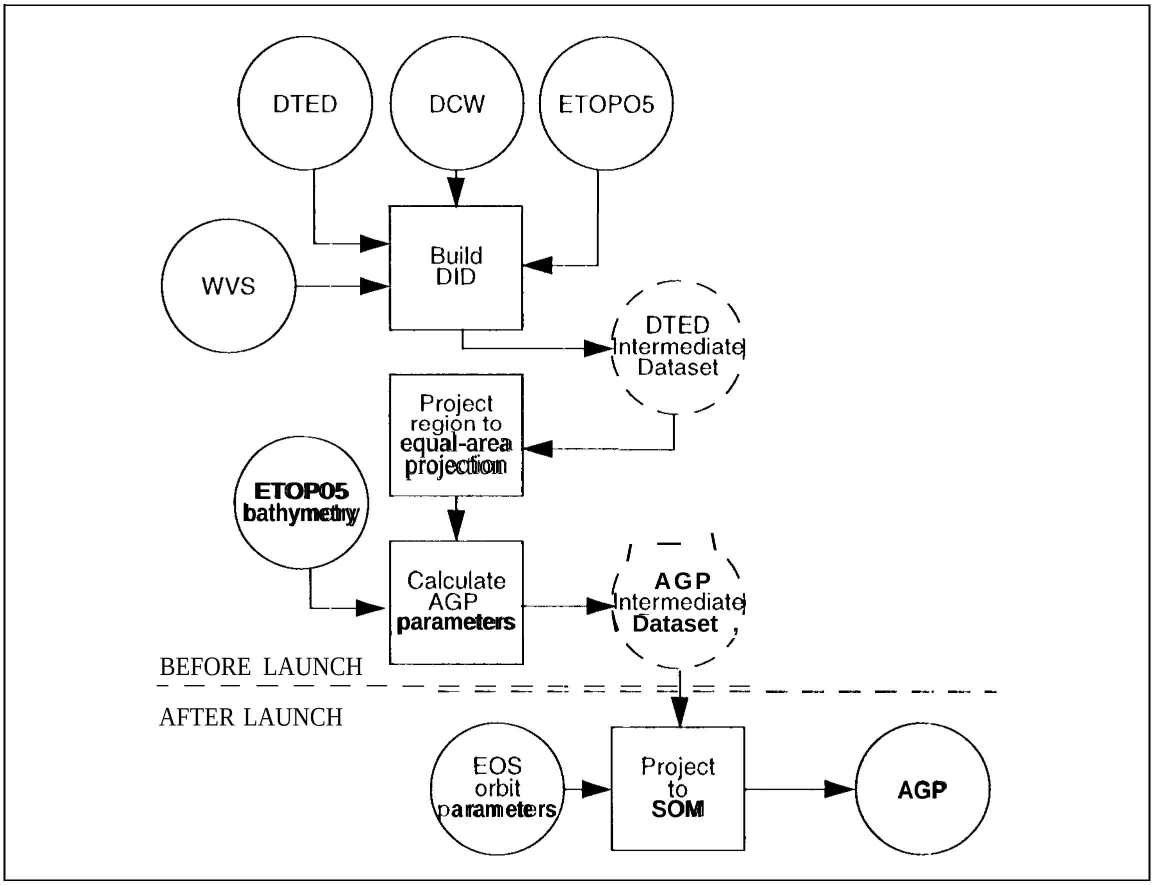


Figure 1: AGP Generation Activities Before and After launch

Mapping Agency (DMA) Digital Terrain Elevation Dataset (DTED) which has been adjusted from Mean Sea Level (MSL) to the WGS84 ellipsoid and normalized between 10 cells by using a block adjustment technique [4]. Additional data sources, such as the DMA Digital Chart of the World (DCW) Hypsography (i.e., vector elevation contours) and ETOPO5 datasets, have also been used to fill in gaps in the DTED In addition to elevation, the DID also currently supplies a land/ocean mask derived from the DMA World Vector Shoreline (WVS) and metadata giving a quality measure and source for each 10 by 10 cell.

After the DID was built, the next step was to project the DID region by region into an equa-area projection. Currently, the Albers I+@d-Area projection has been chosen. All of the remaining parameters of the AGP are then calculated on the equal-ma projection. Also needed at this stage are bathymetry data from ETOPO5 to determine the Dark Water Algorithm Suitability mask. The result is the pm-launch AGP Intermediate Dataset (AGPID). Finally, the parameters are projected to predetermined blocks in a Space Oblique Mercator projection. The after launch EOS orbit parameters arc needed for the SOM projection.

4.0 ALGORITHM INPUT

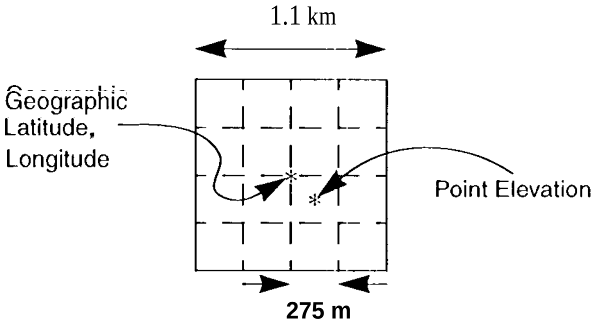
1. DTED: The Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED) Level 1 is a global DEM dataset supplied on CD-ROM. The data are in a Plate Carrée (simple cyclindrical) map projection, The Level 1 post spacing is 3 arc seconds (approximately 100 meters). The horizontal datum is the World Geodetic System 1984 reference ellipsoid. Initially, the vertical datum is Mean Sea Level (MSL). During the construction of the AGP, the elevations are adjusted to the WGS84 ellipsoid.
2. WVS (lancl/water mask): The DMA World Vector Shoreline (WVS) product was used to separate land from ocean/sea areas. The product was derived from digitizing 1:250,000 map sources where available, and 1:389,000 navigation charts when higher resolution products were not available. The vector data have been converted by the Cartographic Applications Group (CAG) at JPL to a raster mask of 1.1 km cells.
3. DCW (hypsography): The DMA had the Digital Chart of the World (DCW) prepared from its global inventory of 1:1,000,000 scale map products. These maps contain elevation contours for every 1000 foot elevation and a file of spot height elevations. Conformity of the elevation model to drainage basin terrain is accomplished by using the DCW hydrographic file of rivm/streams [2]. The resultant elevation model is converted from feet and MSL to meters above the WGS84 ellipsoid.
4. ETOPO5 (elevation and bathymetry): The 143'01'05 is a global dataset originally developed by tbc DMA, and later converted to WGS84 by the National Geophysical Data Center (NGDC). ETOPO5 is grid raster providing elevation above sea level and depth below sca level at 5 arc minute postings (approximately 10 km). The data sources were the 1:1,000,000 series over land (Operational Navigation Chart), and the Nautical Charts available over the ocean.
5. EOS orbit parameters: The SOM map projection requires parameters that desci i be the EOS spacecraft orbit. These include the angle of inclination, the orbit time required for the revolution of the spacecraft, and the geodetic longitude of the ascending node for each of the 233 repeat orbits.

5.0 THEORETICAL DESCRIPTION - CALCULATE AGP PARAMETERS

5.1 Average scene elevation

This is the orthometric height averaged over the SOM grid location measured relative to the WGS84 ellipsoid. It is calculated by taking the mean of all elevation values within the 1.1 km grid on the equal area projection. If sob- 1.1 km elevation values are not available, the nearest elevation value in a lower resolution dataset is used. Since the DID has elevation values recorded relative to Mean Sea Level, geoid undulations are also accounted for, in order to calculate height relative to the ellipsoid.

5.2 Point **elevation**



This is the ellipsoidal (geodetic) height relative to the WGS84 ellipsoid. It corresponds to the points with geographic locations defined to be 137.5 m south and 137.5 m east of the points representing 1.1 km grid centers (see diagram below). In order to obtain the most accurate point elevation given the accuracy of the original source the computation consisted of the following steps: 1) Define the geographic location of the point selected to have point elevation (add oft'sets of 137.5 m to the SOM grid centers). 2) Compute the **latitude and** longitude of these points in order to relate them to the coordinate system of the input DID. 3) use bilinear interpolation to compute the elevation which corresponds to the point defined in 1). This point will be surrounded with 4 elevation postings at 3 arcsec in the DID. These 4 postings are used as input to the bilinear interpolation. 4) From the elevation obtained in 3) subtract the amount of geoid undulation corresponding to this geographic location.

5.3 Standard deviation of scene elevation

This parameter has two possible definitions: I) If sub- 1.1 km spatial resolution data arc used to determine the average scene elevation for the grid location, then this is the standard deviation of those data values 2) in regions where sub-1. 1km data are not available or when less than three values are available to calculate the average scene elevation, a flag will be entered which specifies the data source.

5.4 Regional average scene elevation

This is the orthometric height averaged over a I 6 x 16 SOM grid locations measured relative to the WGS84 ellipsoid. It is calculated by taking the man of all average scene elevation values within the 17.6 km region.

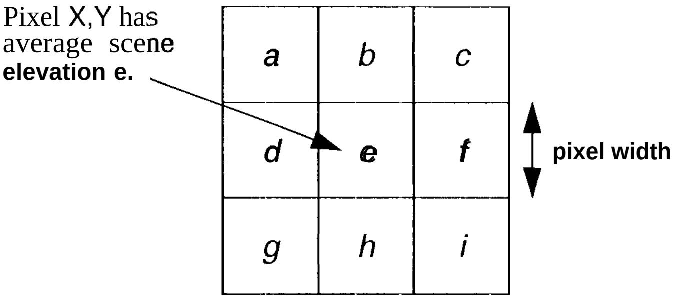
5.5 Regional standard deviation of scene elevation

This is the standard deviation of the 16 x 16 array of 1.1 km data that make up the 17.6 km region.

5.6 Average surface-normal zen it h angle

The average surface-normal zen ith angle represents the average slope gradient angle at the grid location. It is the angle between the vector normal to the best-fit surface using the data input to the average scene elevation calculation and the vector normal to the WGS84 ellipsoid. The algorithm chosen has been determined by the U.S. Army Topographic Engineering Center (T'EC) to have the best performance [5]. This algorithm is also the one used by the ESRI ARC/INFO GIS utility [2].

A 3 x 3 pixel window is used to calculate the slope gradient at each pixel. For a pixel at location X,Y, the aver.ge scene elevations around it are used to calculate the slope gradient as shown below:



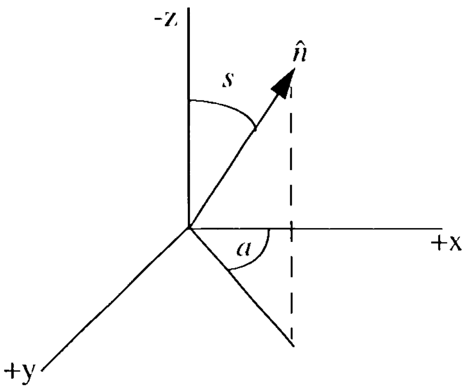
where *a, b, c, d, f, g, h,* and *i* are the average scene elevations of the pixels around it in a 3 *x* 3 window.

First, the average elevation changes per unit of distance in the x and y direction (Ax and Ay) ate calculated as:

$$\Delta x = [(a+2d+g)-(c+2f+i)]/(8 \times w)$$
$$\Delta y = [(a+2b+c)-(g+2h+i)]/(8 \times w) \qquad (1)$$

where w is the pixel width, which is equal to either: 1) $\frac{1.1}{3}$ km, if sub-1.1km data is available, or 2) 1.1 km, otherwise. The average surface-normal zenith angle (slope gradient) in degrees at pixel x,y is then calculated as: $s = \mathrm{atan}\left(\frac{\sqrt{(\Delta x)^2 + (\Delta y)^2}}{2}\right)$

5.7 Standard deviation of seem elevation relative to mean slope



Consider a right-hand local Cartesian coordinate system in which +x points to North, +y points East, and the z-axis is the local ellipsoid normal with +z pointing into the Earth, and -z pointing upward. The normal vector to the plane describing the mean surface slope, $\hat{n}$, is given by:

$$\hat{n} = \begin{bmatrix} \sin s \cdot \cos a \\ \sin s \cdot \sin a \\ -\cos s \end{bmatrix} \qquad (2)$$

If the plane parallel to the mean surface slope goes through an altitude h_0 at the origin (x = y =0), then, for an arbitrary x, y the height on this plane is $h(x, y) = h_0 - \tan s \cdot (x\cos a + y\sin a)$ where s is the average surface-normal zenith angle described in §5.6 and a is the average surface-normal azimuth angle described in §5.8. In order to calculate the standard deviation of the heights relative to the heights on the mean slope surface, after we have sol ved for h_0, s, and a, calculate:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{k} [h_{meas,i}(x,y) - h_i(x,y)]}{k-1}} \qquad \textbf{(3)}$$

5.8 Average surface-normal azimuth angle

The average surface-normal azimuth angle represents the average aspect of the slope at the grid location. It is the angle between the horizontal vector to local North and the horizontal projection of the surface-normal vector, evaluated in the horizontal plane tangent to the WGS84 ellipsoid.

Using the same 3 x 3 pixel window that was used for the average surface-normal zenith angle, the average elevation changes per unit of distance in the x and y direction (Ax and Ay) are calculated as:

$$\Delta x = [(a + 2d + g) - (c + 2f + i)]/(8 \times w)$$
$$\Delta y = [(a + 2b + c) - (g + 2h + i)]/(8 \times w) \qquad (4)$$

where w is the pixel width, which is equal to either: 1) $\frac{1.1}{3}$ km, if sub-1.1km data is available, or 2) 1.1 km, otherwise. The average surface-normal azimuth angle (slope aspect) in degrees at pixel x,y is then calculated as: $a = \mathrm{atan}\left(\frac{\Delta x}{\Delta y}\right)$

5.9 Land/water identifiers

The land/water identifiers are classification masks labelling grid locations with values signifying land, ocean, inland water, ephemeral water, and coastline.

1. Land identifier: Grid is identified as containing all land.
2. Ocean identifier: Grid is identified as containing all ocean.
3. Inland water identifier: Grid is identified as containing all inland water.
4. Ephemeral water identifier: Grid is identified as containing any ephemeral water based on 2 km resolution threshold from the DCW Water Bodies file.
5. Coastline identifier: Grid is identified as containing a mixture of land and ocean or land and inland water.

5.10 Dark Water Algorithm Suitability mask

Grid is identified as either ocean or inland water and is at least 5 km distance from a land grid in any direction and has a water depth of greater than 50 meters as recorded in ETOPO5 bathymetry data.

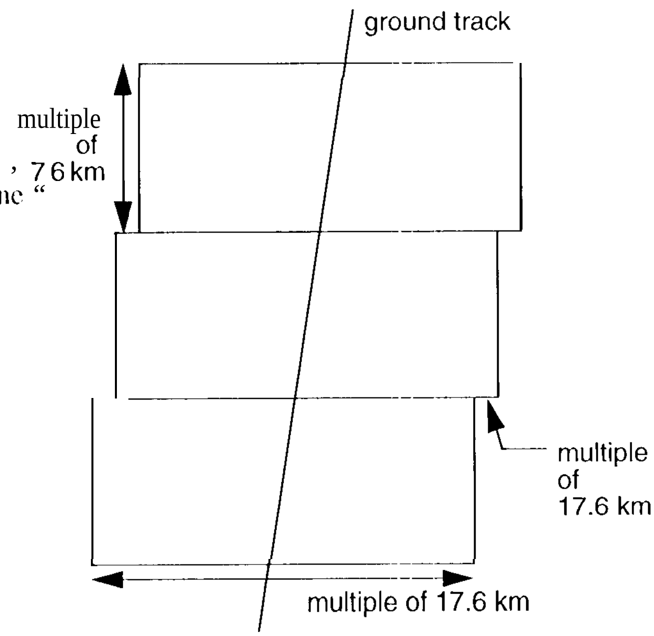
6.0 THEORETICAL DESCRIPTION - PROJECT TO SOM

6.1 Space Oblique Mercator Map (SOM) Projection

The SOM system is a space-based map projection, based on the Oblique Mercator projection, where the reference meridian nominally follows the spacecraft ground track. It provides a mapping from latitude/ longitude to a coordinate system that is approximately aligned with the MISR swath. For the algorithm description of the transformation to the SOM map projection, which is quite complex, the reader is referred to reference [6].

6.2 Calculation of AGP block locations

A conceptual schematic for the calculation to determine the AGP block locations is shown in Figure 2.



Since the MISR instrument acquires data from terminator to terminator during any one orbit, in order for the AGP to cover all possible orbits during a year, the AGP blocks must run from the summer' solstice terminator crossing in the north to winter solstice terminator crossing in the south.

in addition, individual blocks are positioned according to several requirements, shown here at right. Each equal-sized block has a width and a length which is a multiple of 17.6 km. Each consecutive block is centered as closely as possible to the spacecraft ground track, with the rule that any cross-track shift can only be made in multiples of 17.6 km.

7.0 ACKNOWLEDGMENTS

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Figure 2: AGP blocks along an SOM projection